



Washington University
School of Engineering and Applied Science

Power Consumption of Customized Numerical Representations for Audio Signal Processing

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Outline

- Audio Signal Requirements
- Customized Numerical Representations
- SNR and Dynamic Range
- Design of Computation Structures
- Power Consumption Results
- Summary and Conclusions



Audio Signal Applications

- Music
 - MP3 players
- Speech
 - communications equipment
 - hearing aids (our target application)
- Signal requirements to understand speech
 - ~30 dB SNR over entire dynamic range
 - ~100 dB dynamic range
- Power consumption critical for all of above



Customized Numerical Representations

- 16-bit integer is traditional for audio
 - 90 dB dynamic range, SNR from 0 to 90 dB
- Logarithmic representation more closely mimics human perception
 - Loudness response is highly non-linear
 - SNR is relatively constant across dynamic range
- Floating point representations are partially logarithmic and partially linear
 - 32-bit IEEE standard is more than is needed
 - Tailor choice for number of bits in exponent and mantissa to needs of application



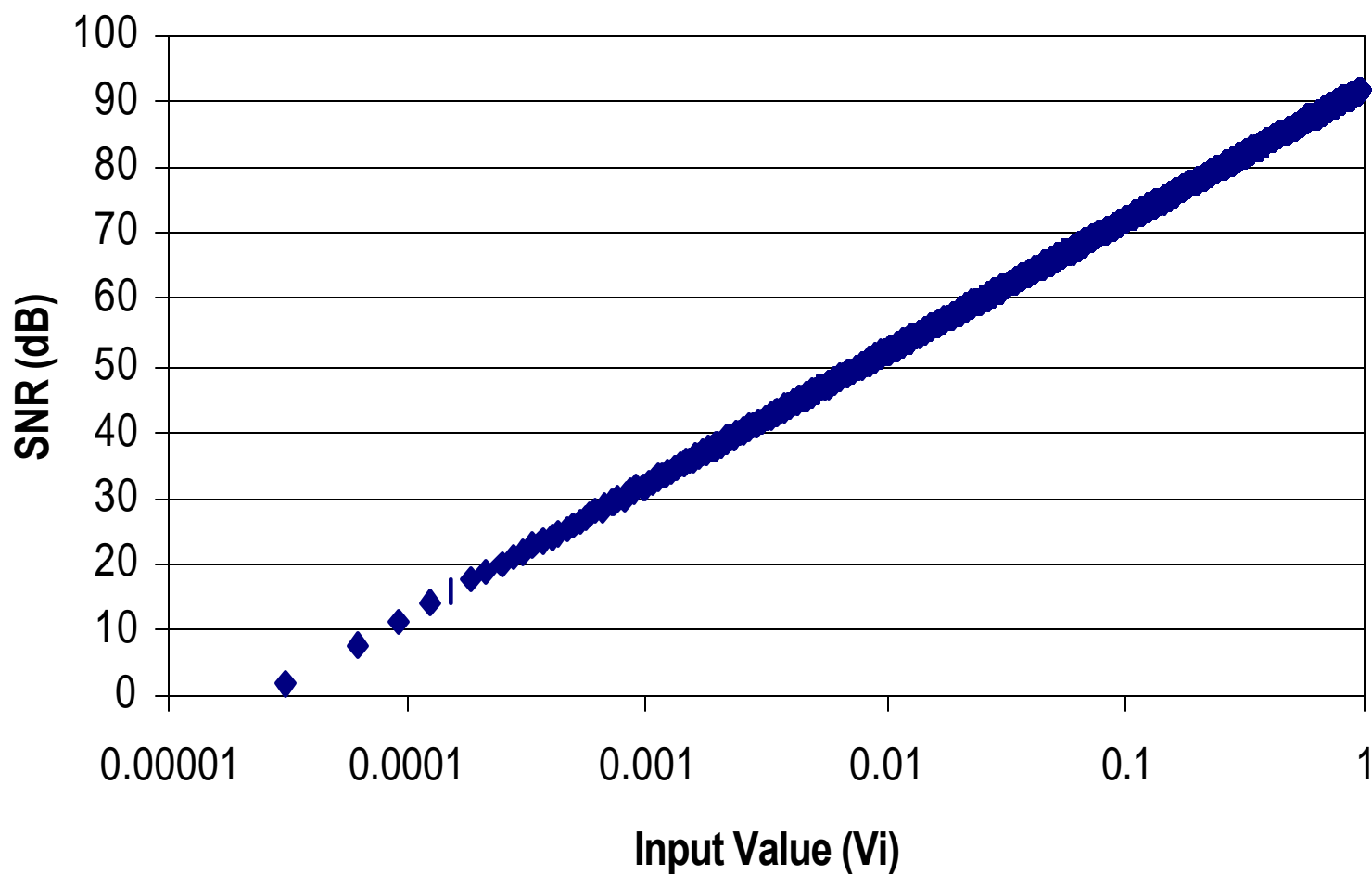
SNR and Dynamic Range

$$\text{SNR (dB)} = 20 \cdot \log_{10} \left(\frac{\frac{V_i}{2\sqrt{2}}}{\frac{V_{i+1} - V_i}{\sqrt{12}}} \right)$$

$$\text{Dynamic Range (dB)} = 20 \cdot \log_{10} \left(\frac{V_{\max}}{V_{\min}} \right)$$

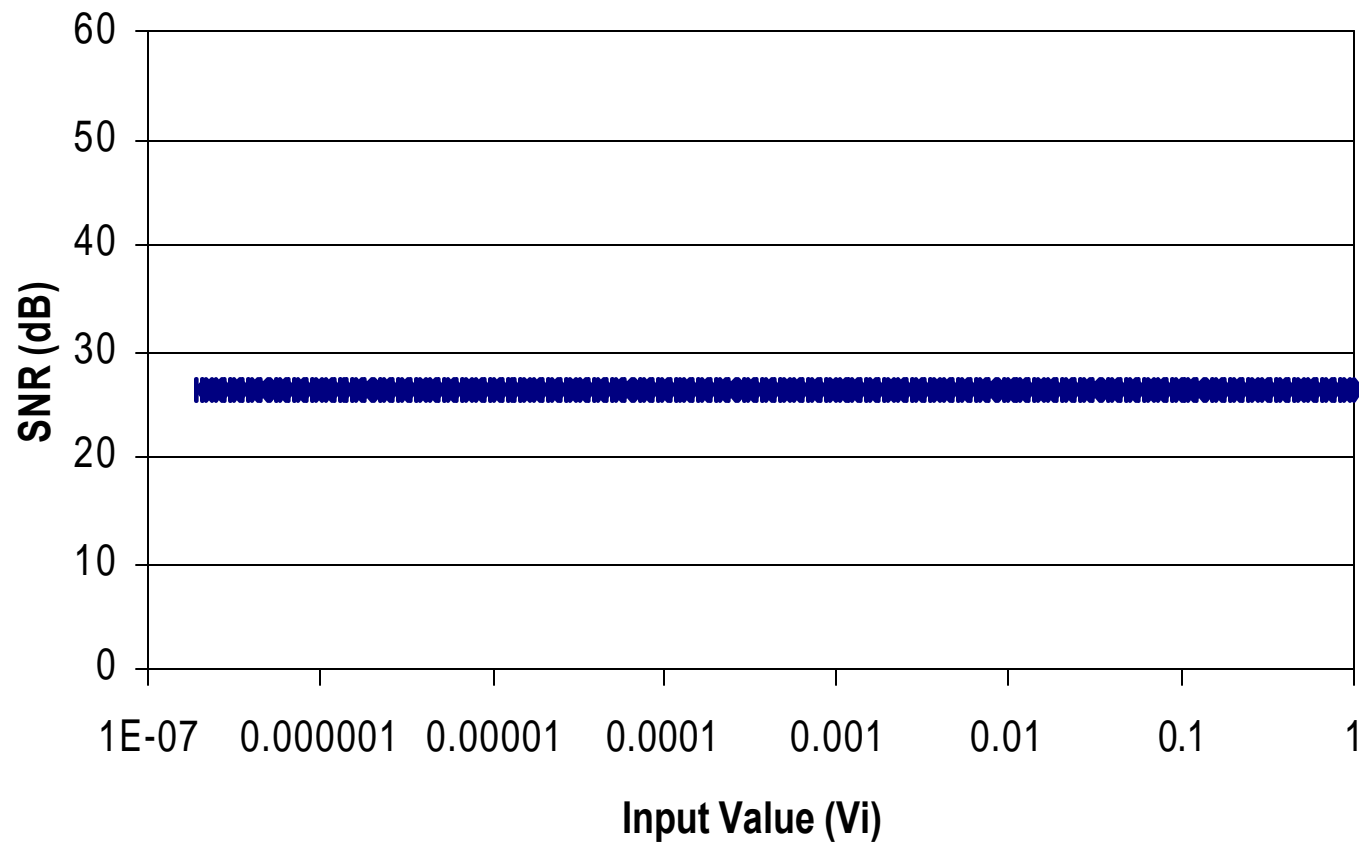


16-bit Integer SNR





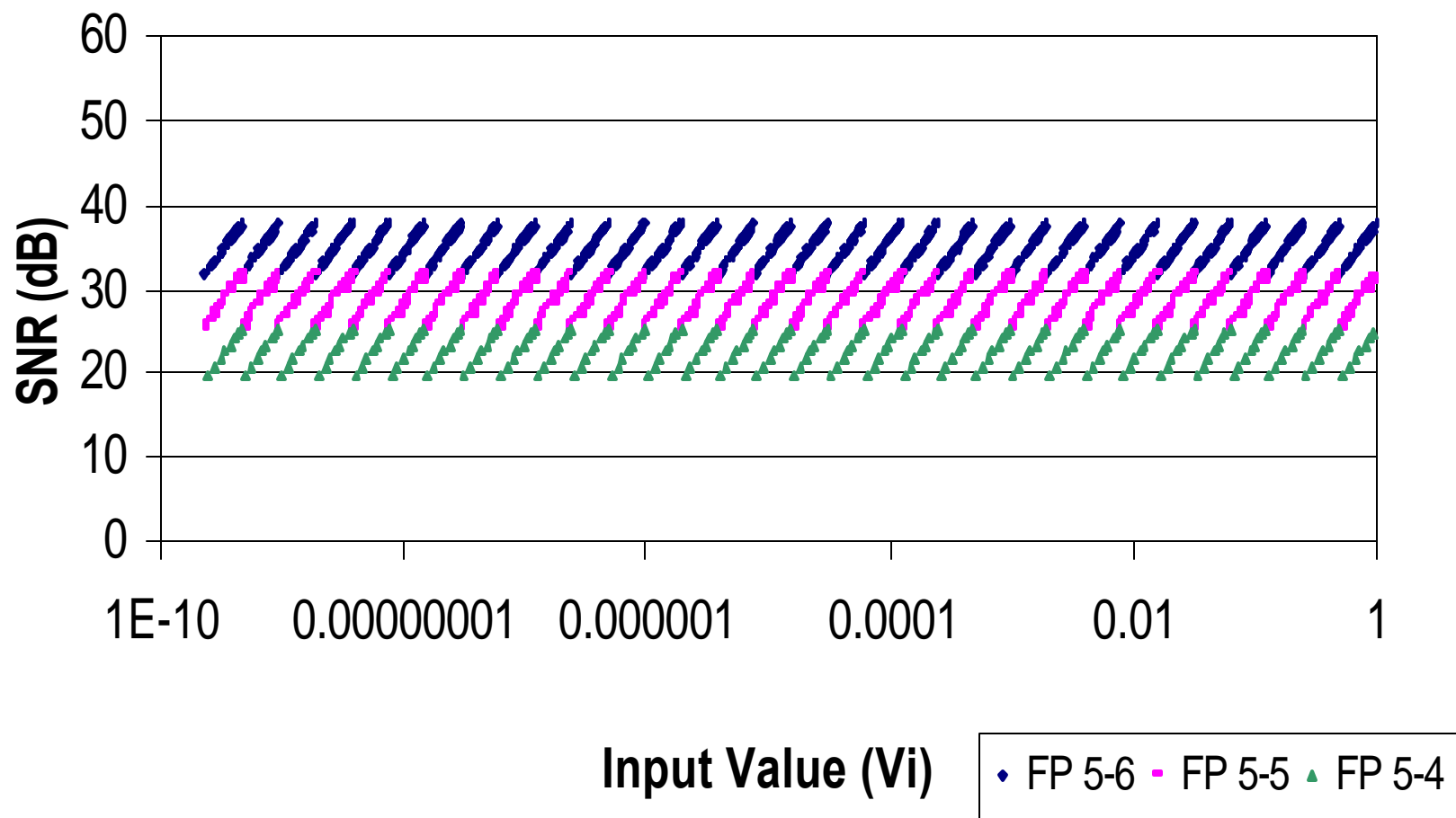
9-bit Logarithmic SNR





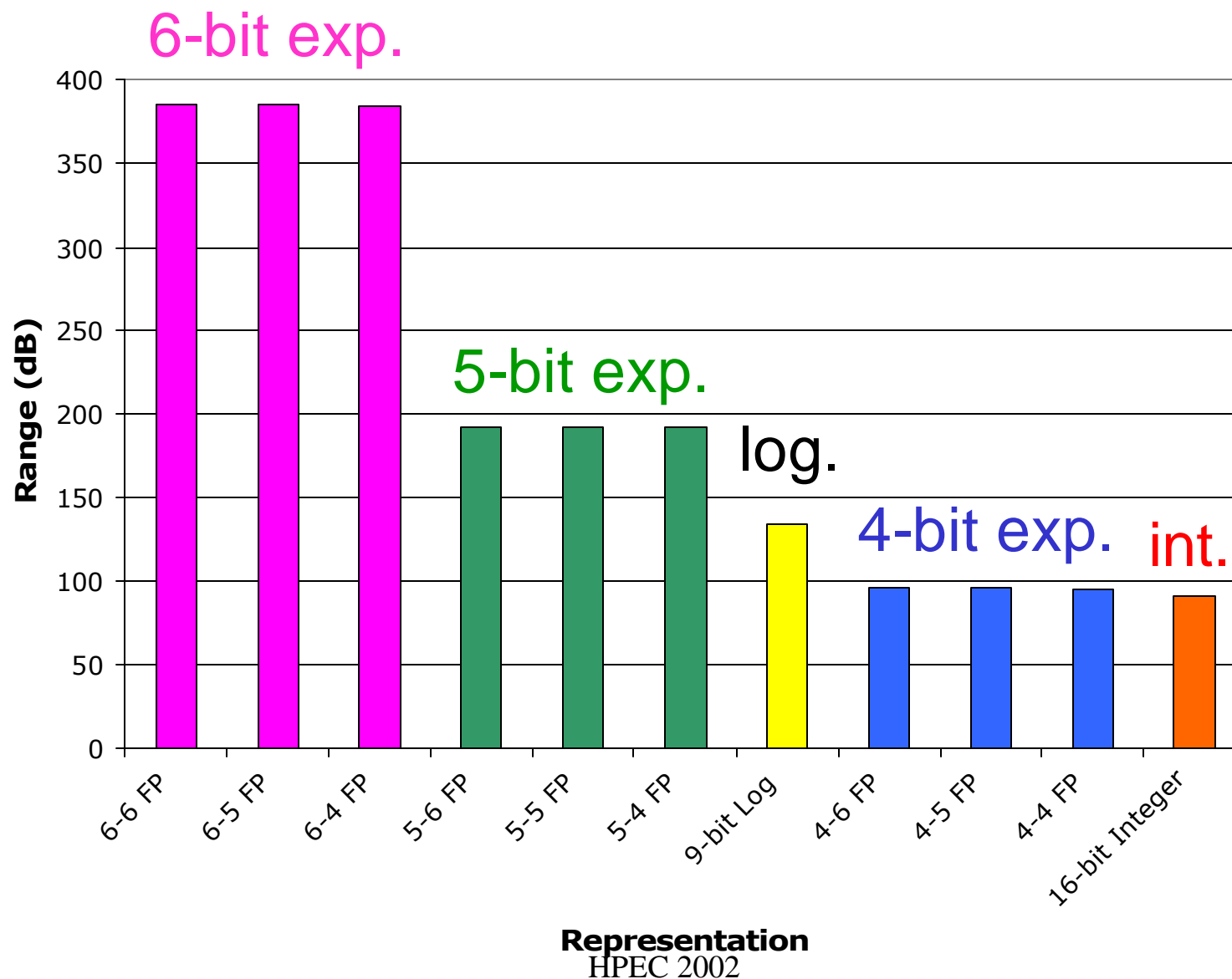
Floating Point SNR

5-bit exponent – 4, 5, and 6-bit mantissa



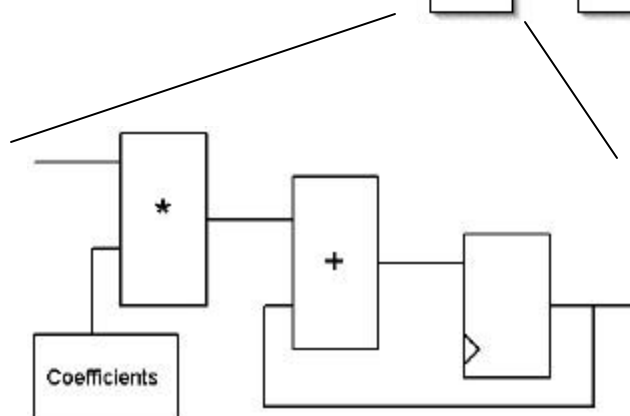
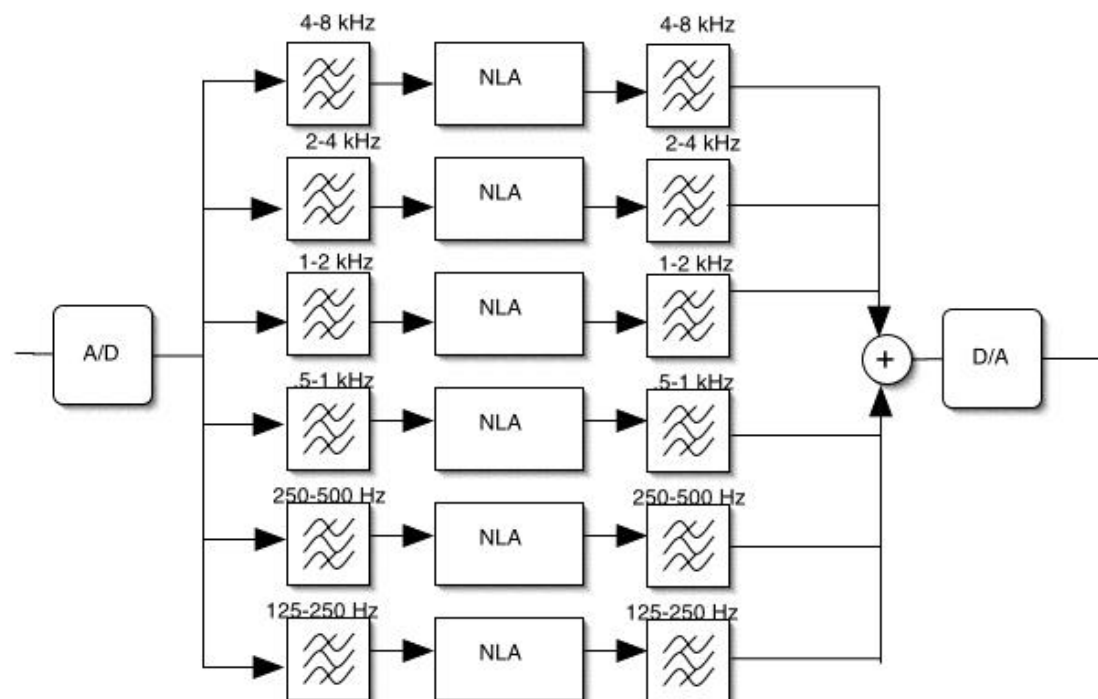


Dynamic Range





Hearing Aid Architecture



Most of the computations the hearing aid performs are multiply-accumulates.

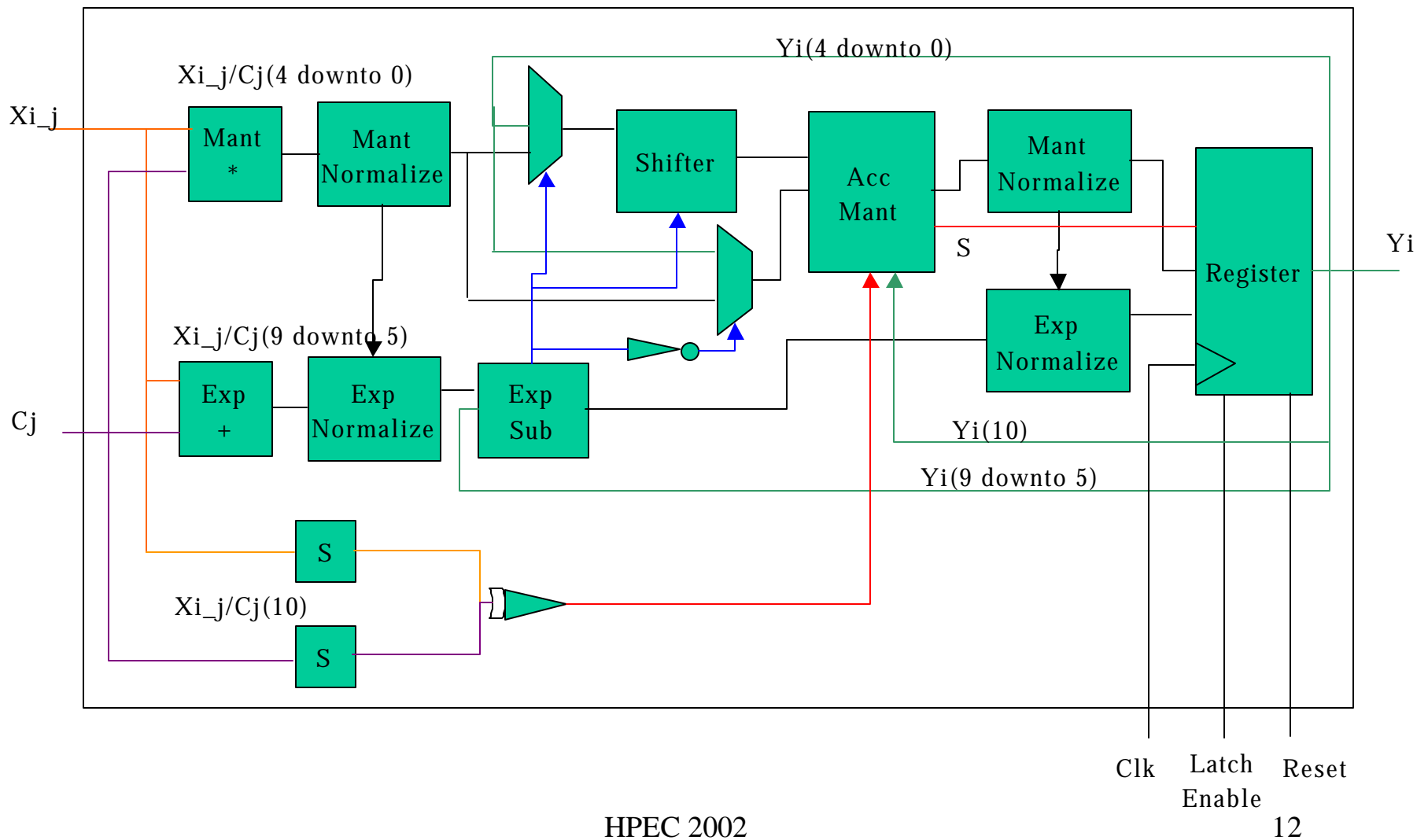


Floating Point MAC Design

- Traditional structure for floating point hardware computations
- Perl script generates synthesizable VHDL code for specific exponent and mantissa size
- Small size of mantissa implies lower power multiplier hardware



Floating Point MAC





Logarithmic MAC Design

- Multiply function provided by an adder:

$$\log(A \times B) = \log(A) + \log(B)$$

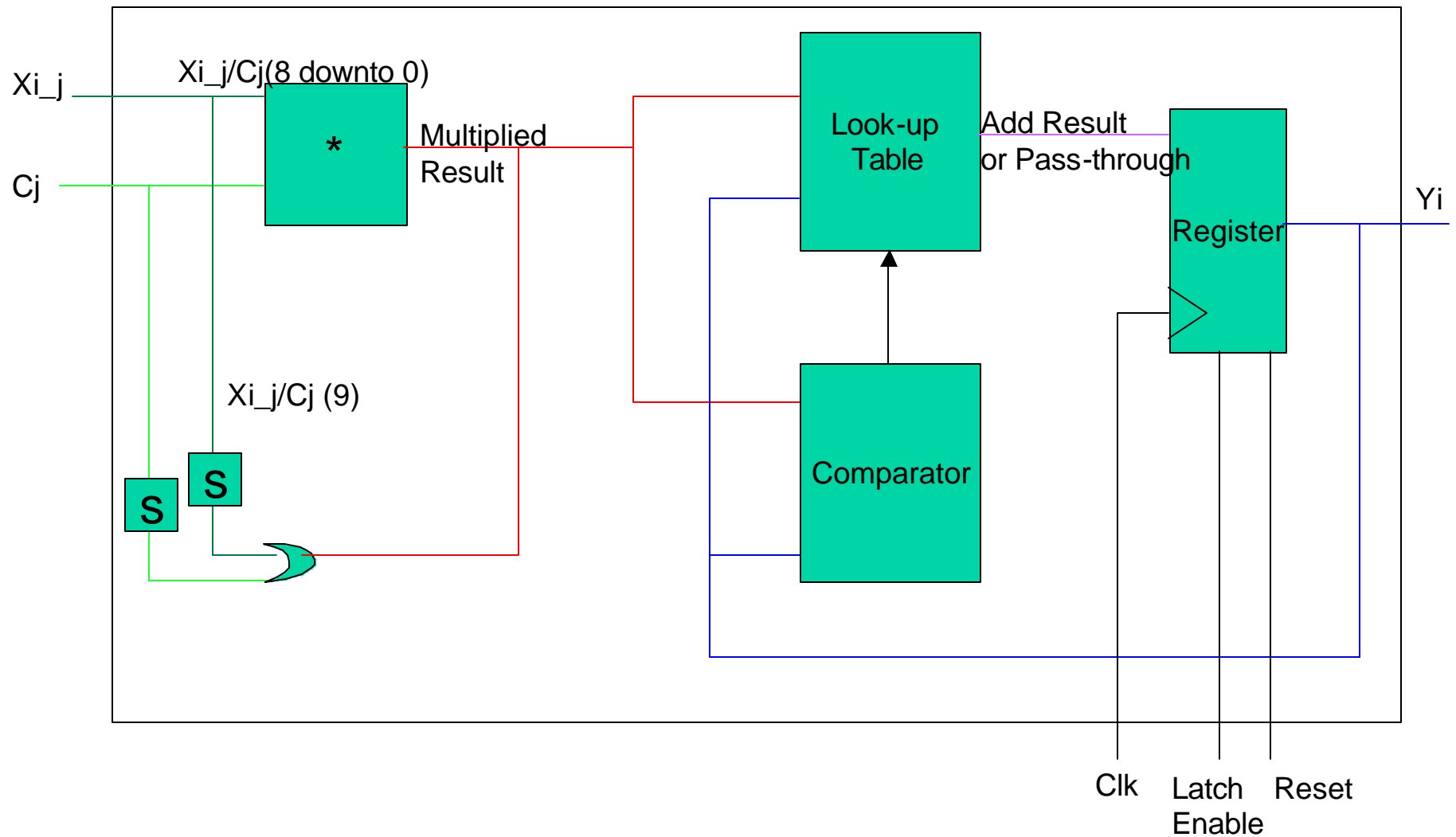
- Addition function exploits the following relationship:

$$\log(A + B) = \log(A) + \log\left(1 + \frac{B}{A}\right)$$

- Last term implemented via a lookup table

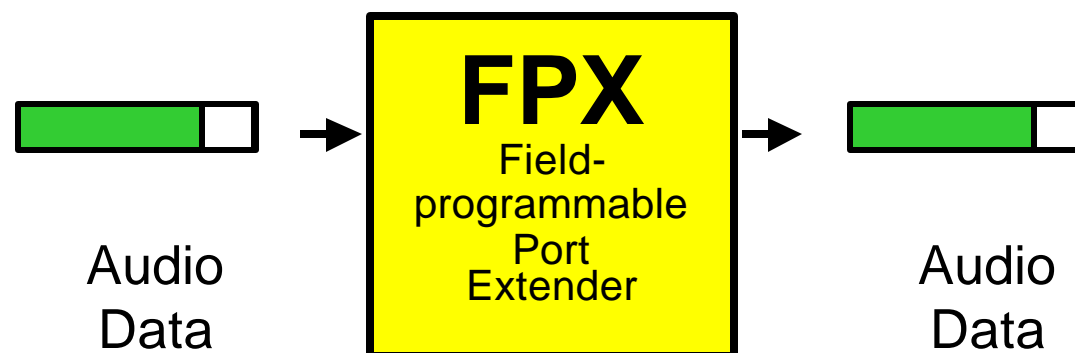
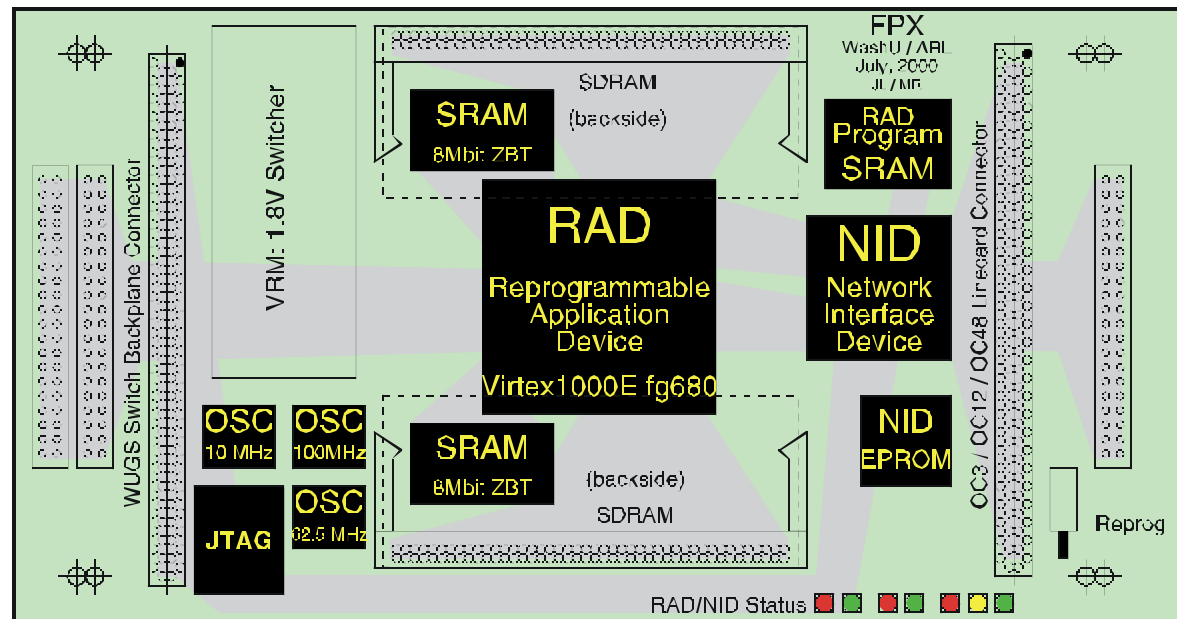


9-bit Logarithmic MAC



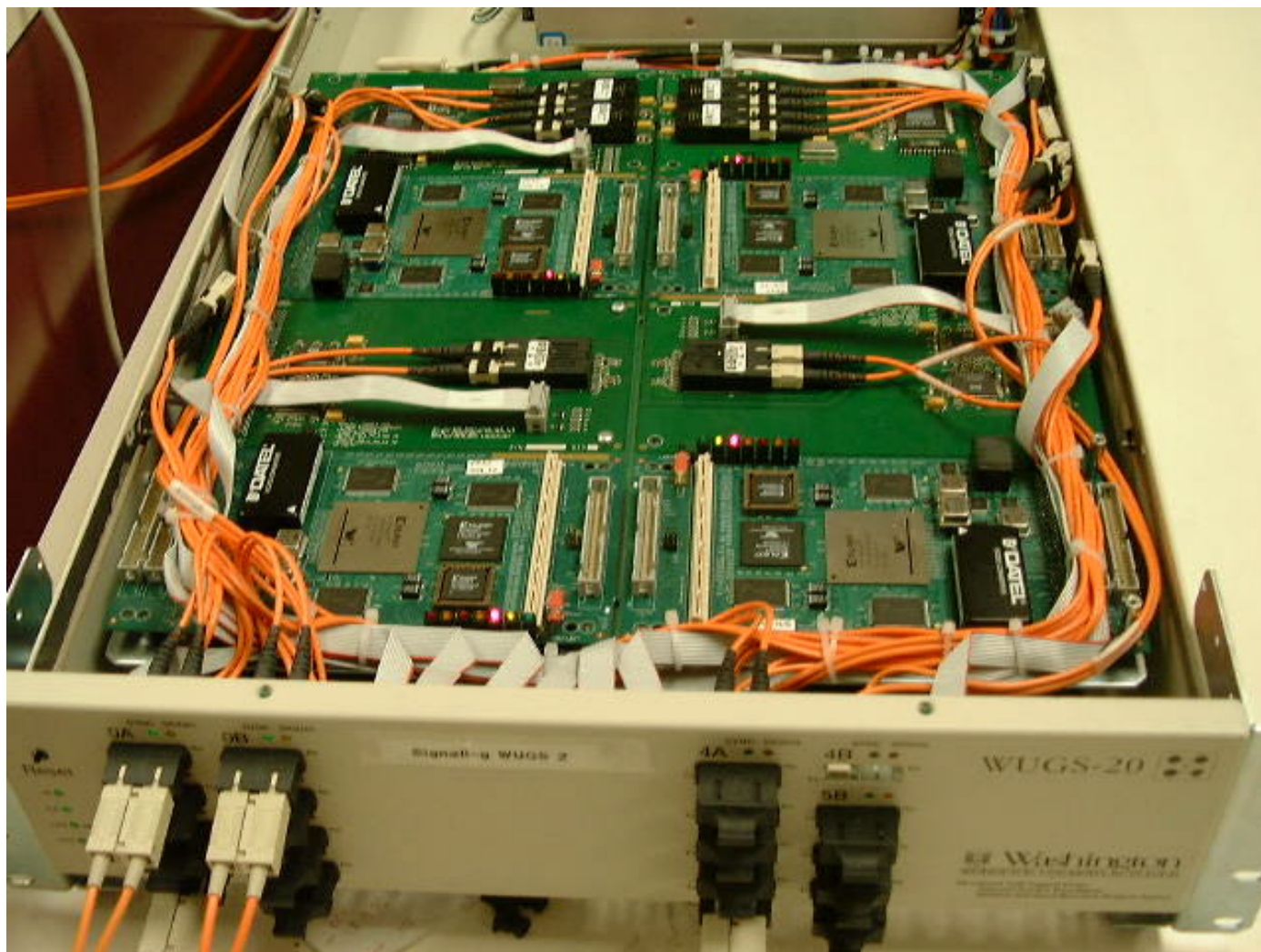


Verification Via FPX Platform



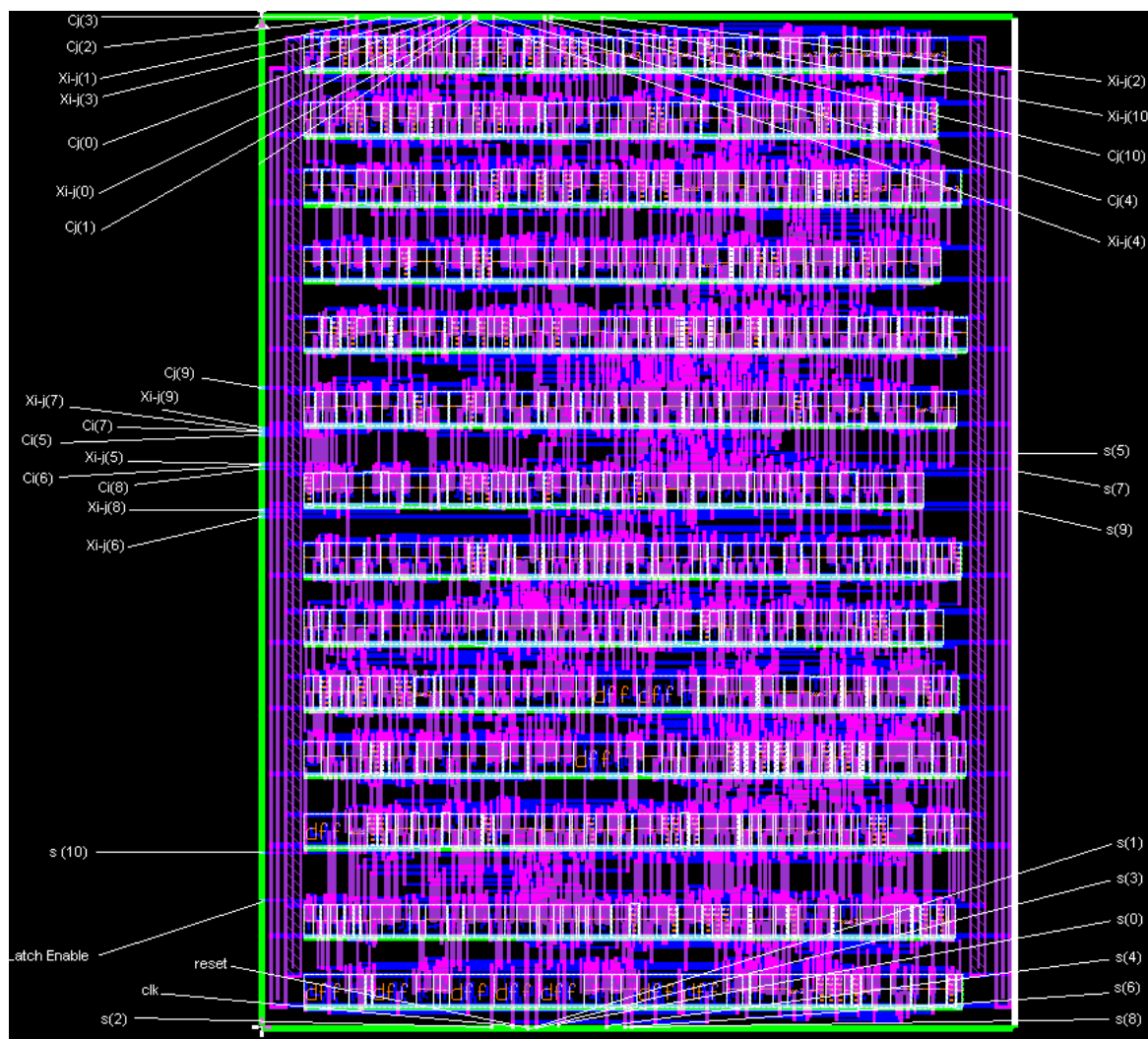


FPX Platform





Layout



- AMI 0.5 μ m process
- ADK library from Mentor Graphics HEP
- 5-5 floating point MAC is shown



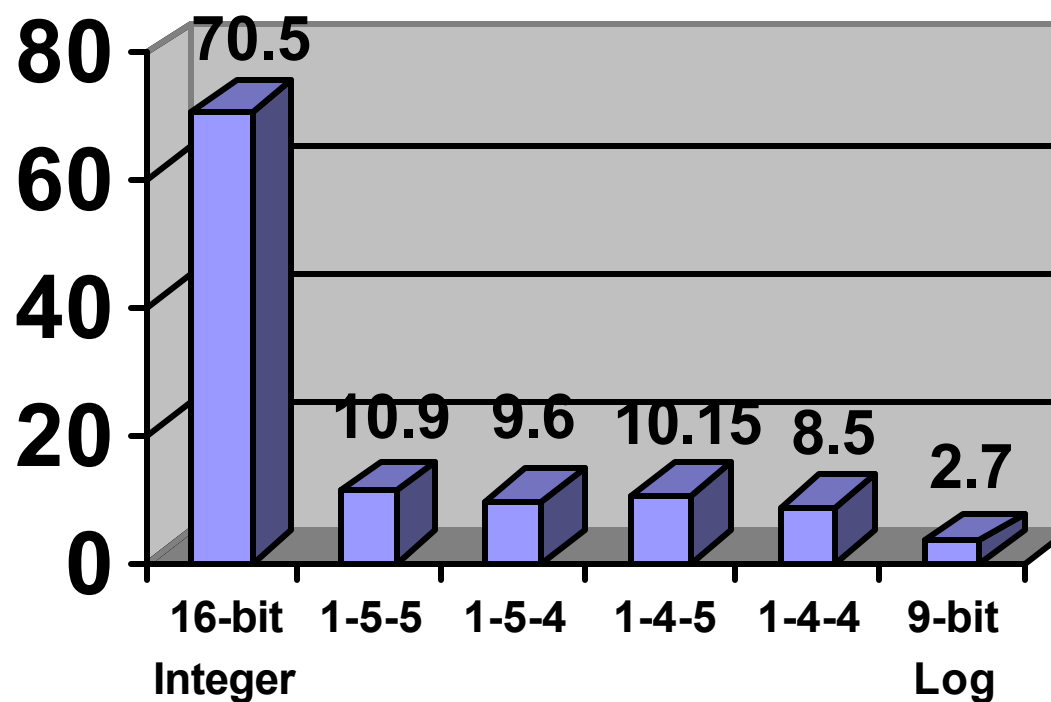
Power Estimation via Simulation

- Simulate using Mentor Graphics MACH-PA
 - Spice-level simulation tool
 - Driven by extracted layout
- Focus on Multiply-Accumulate units
 - Random input vectors
 - Simulation provides current usage
- $P = IV$ provides power results



Power Consumption

**Average
Power
(mW)**



**Numerical
Representation**



Summary and Conclusions

- Customizing a numerical representation to the specific needs of an application can have tangible benefits
- Several 9 or 10-bit representations have improved SNR and dynamic range for audio speech applications relative to traditional 16-bit integers
- Both customized floating point and logarithmic representations have been considered
- Power savings are significant



For Further Information

<http://www.ccrc.wustl.edu/hearingaid>

or

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